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THE WATSON ASTEROIDS.

By Burt L. Newkirk.

(Read at the meeting of the Society held in Berkeley January 30, 1904.)

James C. Watson was born in the province of Ontario, Canada, January 28, 1838. He graduated at the University of Michigan in 1857, and became Professor of Astronomy and Director of the Observatory of that institution six years later. He was one of our most prominent astronomers, having written a book on theoretical astronomy which is still very widely used in the United States. He died in 1880, at the age of forty-two years. During the course of his scientific career he discovered twenty-two asteroids, and at his death left a sum of money as an endowment fund, the income from which should be used to pay for certain investigations and computations which it is necessary to make in order that these asteroids may not be lost to the scientific world.

Beside the well-known greater planets the Sun's system contains a host of very minute planets called asteroids. They revolve about the Sun in the space between the orbits of *Mars* and *Jupiter*. The first one of these to be discovered was found upon the first night of the nineteenth century, the night of January 1, 1801. This is the asteroid *Ceres*, and it is the brightest, and presumably the largest, of the group, having a diameter of 600 miles. Since the introduction of photographic methods in the search for these bodies, their discovery has been made comparatively easy, and something over five hundred of them have already been found, every year adding twenty or thirty to the list. At the time of Watson's death, in 1880, less than two hundred had been found. The smallest of these bodies are probably nothing more than great rocks, ten or fifteen miles in diameter. Smaller asteroids than these undoubtedly exist, but are so excessively faint as to elude discovery.

Of all the planets of the Sun's system these asteroids offer the greatest difficulties in the matter of the investigation of their orbits. We say, roughly speaking, that the planets move about the Sun in elliptical orbits; but, more accurately speaking, none of the bodies composing the Sun's system move in ellipses. According to NEWTON's law of gravitation, every particle of matter attracts every other particle. If the Sun were attended by one planet only, this planet would move in an ellipse, but since each planet is attracted not only by the Sun, but also by all the other planets, its path is a curve of corresponding complexity. Since the Sun's attraction is generally by far the most powerful of all the forces acting upon any one planet, it is convenient to think of the actual orbit described by a planet as a " disturbed ellipse," as we express it. We picture to ourselves an ellipse which nearly coincides with the actual orbit, and in which the planet would move if the attractive forces of the other planets should at some particular instant cease to operate. The departure of the true orbit from this assumed ellipse, due to the disturbing action of the other planets is called the perturbation of the planet under consideration. The only reason for taking an ellipse as a starting-point in the discussion is one of convenience. A circle, which is a simpler curve from a mathematical point of view, might answer the purpose in some cases better than an ellipse, and for other purposes it is advantageous to take as a starting-point a curve of greater complexity. I refer to the " periplegmatic " curves used by GYLDÉN, which represent the path of the planet throughout a long period of years much better than any ellipse could, but seem to possess no advantages in tracing the planet's motion for a short period of time. It is a comparatively simple matter to compute an elliptic orbit, but to investigate the deviations from this orbit—i. e. the perturbations of a planet—is a task requiring in some cases a tremendous amount of labor and study.

The mathematical difficulties of the problem are such that no general method can be employed for computing the orbits of all the planets. Each planet must be treated with reference to the special difficulties which it presents, and this necessitates an intelligent and discriminating study of the various methods used in investigations of this nature, their advantages and their limitations.

The method employed in any particular case must not only be mathematically correct, but it must also be capable of yielding the desired results with the required degree of accuracy and with a minimum of numerical computation. The method of most general application is one developed by HANSEN, and modified by HILL, NEWCOMB, and others. Newer methods which possess special advantages in certain cases have been developed by GYLDÉN, BOHLIN, and BRENDEL. These latter methods are, however, comparatively untried, and it has been found necessary here in the asteroid work at Berkeley to revise BOHLIN'S method to some extent, before employing the formulæ given. Upon opening correspondence with BOHLIN, whose method has been used on some asteroids here, Professor LEUSCHNER found that BOHLIN himself had arrived at the same conclusion and was at work upon a revision of his theory.

In the case of the asteroids the problem presents special difficulties because of the proximity of *Jupiter,* which is the largest planet, and exerts a very powerful disturbing force. In most cases, in fact, unless a high degree of accuracy is required, the effect of all the other planets combined is a negligible quantity as compared with the perturbations produced by *Jupiter.* Difficult as the problem is, it is however absolutely necessary to compute the perturbations if we would keep the asteroids from retiring again into the oblivion from which their discoverers drew them. It is not possible to predict the motion of an asteroid ten or fifteen years in advance with sufficient accuracy to permit of its being found again at the end of that time without serious difficulty unless this work is done.

In the light of these remarks, Professor WATSON'S object in endowing the twenty-two asteroids discovered by himself will be clear. If their perturbations are not derived, his asteroids will be lost to the world in a few years, but, thanks to the fund he has bequeathed for this purpose, it will be possible to predict their motion for fifty or seventy-five years in advance with sufficient accuracy to enable astronomers of the future to find them again when they are wanted without serious difficulty. One of the twenty-two must be excepted from this statement. The asteroid *Aethra,* whose original path passed close to that of *Mars,* has suffered such violent perturbation that the form of its orbit has been greatly changed, and it has not been identified since, in spite of the diligent search which has been made for it. The tracing of the motion of this planet by means of a special mathematical discussion, which will be an exceedingly difficult matter, is to be undertaken by

Miss HOBE, who is now engaged with me upon the perturbations of the other asteroids, under the direction of Professor LEUSCHNER.

Since Professor WATSON's death, in 1880, the trustees have been trying to carry out the desire expressed in his will, by preparing tables by means of which the motion of these asteroids can be predicted for, say, fifty years in advance, with sufficient accuracy to permit of their being readily found. Up to two years and a half ago, when the work was undertaken by this department, considerable had been done, but little was ready for publication. Since that time the perturbations of ten planets have been computed here in Berkeley, and those of two more are nearing completion. Five others are to be treated by BOHLIN's method, the work on these being already under way: the four remaining asteroids have been made the subject of investigation by other astronomers in Europe and America.

Perhaps the most important result of the investigations of the orbits of the Watson asteroids is the light thrown upon the whole subject of asteroid orbits and the methods best adapted to the various cases that arise. The treatment of twenty-two asteroids yields data which will be very valuable in the solution of one of the great problems which now confronts mathematical astronomy,—namely, that of providing tables by means of which the position of any one of the known asteroids may be found without excessive labor.

Before our tables for finding the planets in future years can be finished it will be necessary to compare the results of our investigations with observations. It is possible by this means greatly to improve the results of the numerical work. For this purpose the photographic telescope and Repsold measuring apparatus will be available. With the help of these instruments we shall be able to observe the positions of the asteroids, and a comparison of observations with theory will lead to a final improvement of the tables before publishing them.

The Watson trustees have, as may be imagined from the long time that has elapsed since Professor WATSON's death without the completion of the task, had great difficulty in getting the work done satisfactorily. They have, however, been very well pleased with the progress made here by Drs. CRAW-

FORD and ROSS, under the supervision of Professor LEUSCHNER, and have now turned the whole work over to the latter to be completed and prepared for publication. The work is being carried on under the auspices of the National Academy of Sciences, and the present Watson trustees are: Professor SIMON NEWCOMB (chairman), Professor LEWIS BOSS, and Professor W. L. ELKIN. It is their intention to have all the results published in due time. It has, however, seemed fitting upon this occasion to offer to those interested in the Berkeley Astronomical Department this brief statement of our connection with the undertaking.

THE PHOTOGRAPHIC EQUATORIAL OF THE STUDENTS' OBSERVATORY.

BY ALLEN F. GILLIHAN.

(Read before the meeting of the Society, held in Berkeley, January 30, 1904.)

It has been demonstrated by Professors BARNARD, WOLF, and others, that lenses of the portrait type, and of large aperture, on account of their great light-grasping power, are very suitable for obtaining, with long exposures, photographs of very faint stars. Such a lens has been in the possession of the Students' Observatory for some years, but for lack of a suitable mounting, little work could be done with it. From time to time, however, it has been strapped to the tube of the 6-inch equatorial, together with its wooden camera, but as, until recently, the driving clock of this instrument did not perform well, and as there was no slow motion in hour-angle, this mounting was entirely unsuitable for photographic purposes. The need for a suitable mounting was thus greatly felt, particularly so in connection with the department's work on the Watson asteroids, it being the intention to verify by photographic observations their computed positions before tables for these asteroids are constructed.

Correspondence with various instrument-makers developed the fact that a mounting such as was desired could be constructed only at a greater loss of time and cost than seemed desirable. The department, therefore, decided to attempt the construction of a suitable equatorial mounting here in Ber-